Lat 41.2813 Lon -120.8273

Forest Health Protection

Pacific Southwest Region
Northeastern California Shared Service Area

Date: October 25, 2016
File Code: 3420

To: District Ranger, Big Valley Ranger District, Modoc National Forest

Subject: Stand conditions and white fir mortality within the proposed Kresge Project (FHP Report NE16-12)

Report Summary

- White fir abundance has increased dramatically within the proposed project area due in large part to fire exclusion. White fir is now the dominant conifer species in many stands that were historically dominated by fire-adapted ponderosa and Jeffrey pine.
- Diseases such as Heterobasidion root disease and white fir dwarf mistletoe are present in many stands.
- Fir engraver beetle-caused white fir mortality has increased over the past three years (Figure 1). Mortality is greatest in denser stands and in areas where precipitation during drought periods is insufficient for supporting stands of white fir over the long-term.
- This current white fir mortality event follows a similar drought related mortality event from 1987-1992, showing that unsustainable stand conditions continue to exist in many locations on Big Valley Ranger District.
- Green tree thinning and sanitation are highly recommended throughout the project area to greatly reduce the abundance of white fir, reduce surface and ladder fuels and begin to restore what was once a fire-adapted pine dominated ecosystem.
- All stands, with few exceptions, need to be managed for the pine component. Without a major effort to reduce the abundance of white fir, periodic outbreaks of fir engraver beetle in response to drought will continue to contribute to excessive fuel loading and ultimately result in stand replacing wildfire.

Figure 1. Dead and dying white fir on Manzanita Mountain. July 21, 2016.

Background

At the request of John Landoski, District Culturist, Big Valley Ranger District, Danny Cluck, Forest Health Protection (FHP) Entomologist, and Bill Woodruff, FHP Plant Pathologist, conducted a field evaluation of the Kresge project area on July 21, 2016. The objective of this visit was to evaluate existing stand conditions and current white fir mortality. Treatment alternatives were discussed in the field and are documented in this report. Recommendations provided in this report will assist in the formulation of silvicultural prescriptions aimed at reducing overall stand density with an emphasis on greatly reducing the relative abundance of white fir. John Landoski accompanied us in the field.

Description of the project area

The Kresge project is located approximately 8 miles northeast of Adin, CA at elevations ranging between 4,800 and 7,020 feet (41.2813° N and 120.8273° W). Annual precipitation ranges between 20 and 35 inches (Figure 2). Forest cover is a combination of native stands and pine plantations. The native stands consist primarily of white fir (*Abies concolor*) with lesser amounts

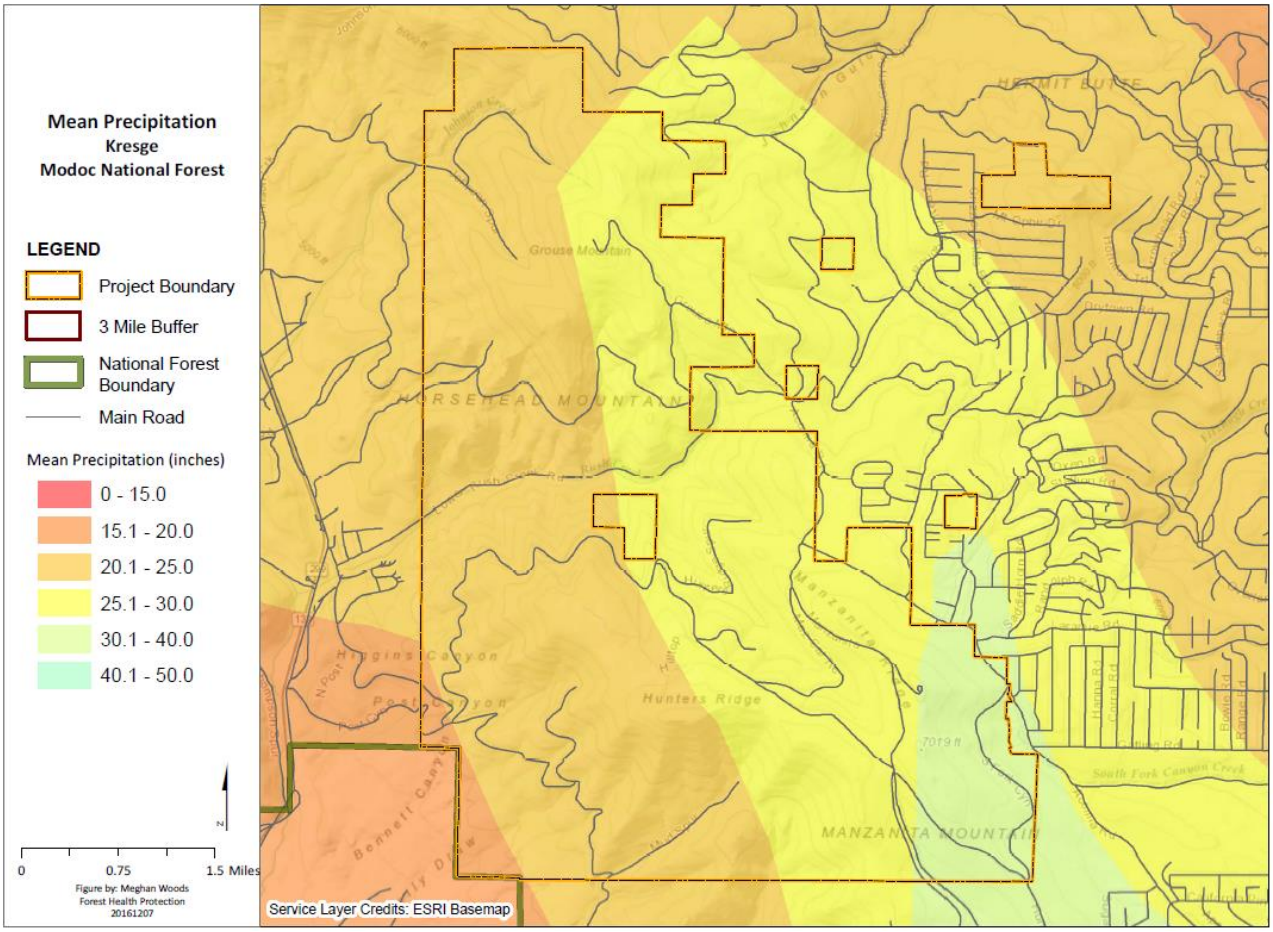

Figure 2. Mean annual precipitation for the Kresge project and surrounding area.

of ponderosa pine (*Pinus ponderosa*), Jeffrey pine (*Pinus jeffreyi*) and incense cedar (*Calocedrus decurrens*). Most forested areas are densely stocked, have experienced elevated levels of tree mortality associated with insects, pathogens and drought and contain high numbers of standing and down dead trees.

Forest insect and disease conditions

Bark beetle activity observed during the site visit was primarily on white fir where fir engraver beetle (*Scolytus ventralis*) is causing high levels of tree mortality throughout the project area. (Figures 3). White fir mortality was also associated with Heterobasidion root disease (caused by *Heterobasidion occidentale,* formerly referred to as S-type annosus root disease) and white fir dwarf mistletoe (*Arceuthobium abietinum* f. sp. *concoloris*) in some locations (Figures 4 and 5).

Figure 3. High numbers of dead white fir killed by fir engraver beetle.

Figure 4. Older fruiting bodies of *Heterobasidion occidentale,* the cause of Heterobasidion root disease.

Figure 5. Dwarf mistletoe on white fir branch.

Figure 6. Jeffrey pine killed by Jeffrey pine beetle. Tree was crowded out by competing white fir.

A few Jeffrey pine growing within dense stands of white fir were being attacked and killed by Jeffrey pine beetle (*Dendroctonus jeffreyi*) (Figure 6).

Aerial detection surveys (ADS) in 2016 also mapped high levels of white fir mortality caused by fir engraver beetle throughout the project area (Figure 7).

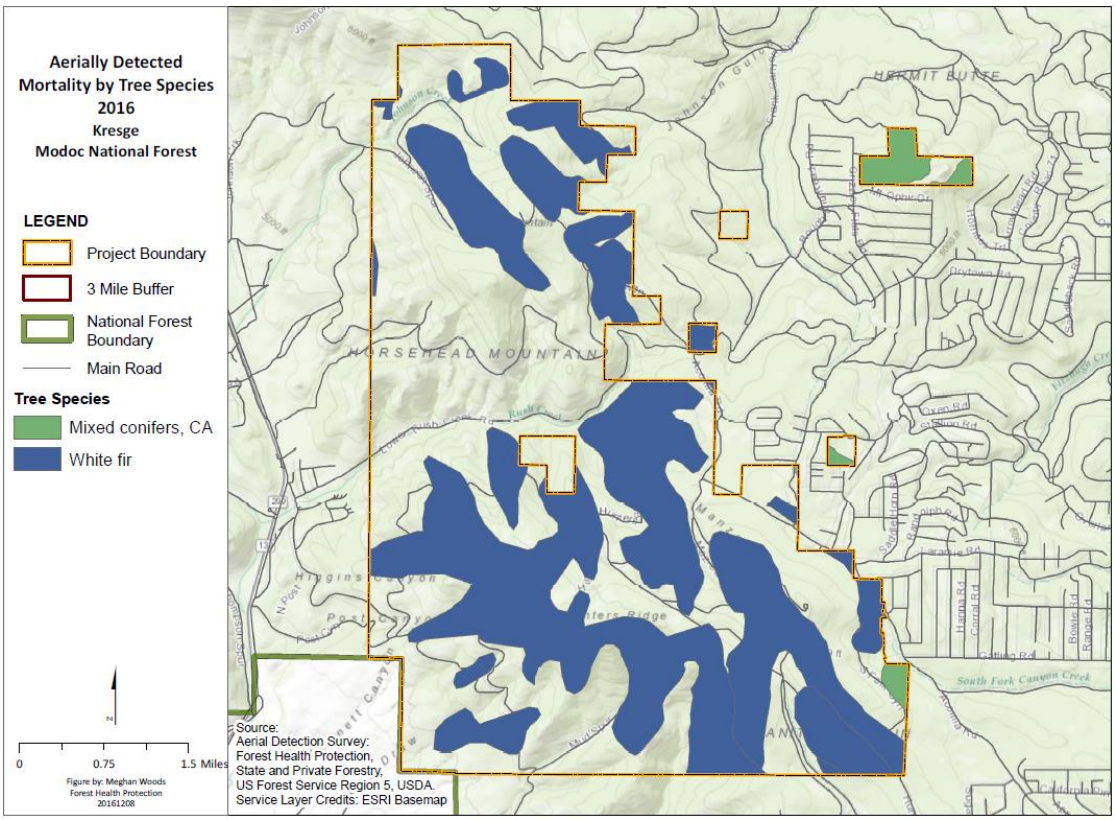

Figure 7. Extent of white fir and other conifer mortality in 2016 as detected by ADS flight.

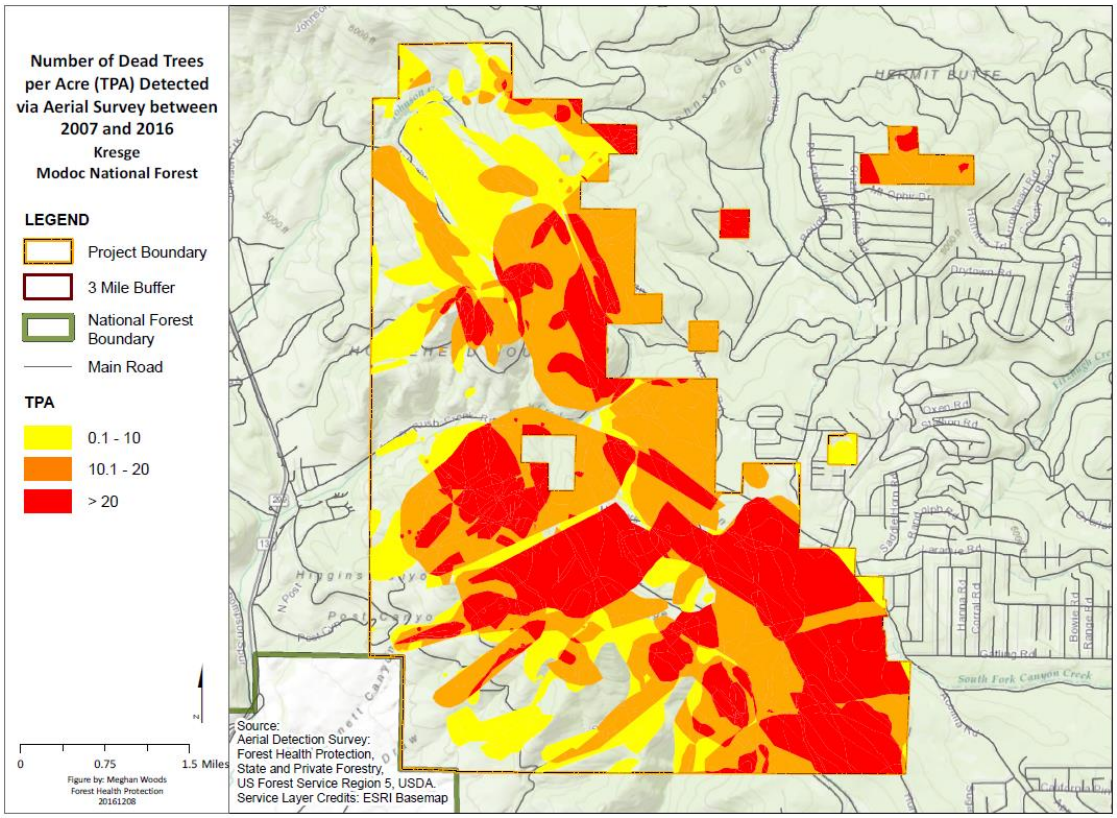

Figure 8. Number of dead trees per acre from 2007 to 2016.

Stand conditions and mortality related to recent and future climate trends

Many of the forested areas in Kresge project area are overstocked and have exhibited elevated levels of tree mortality caused by bark beetles, especially during periods of drought (Figures 8 and 9, Table 1). This mortality combined with high stand density has resulted in heavy fuel loading in many areas and a corresponding increase in potential fire behavior. Kresge plot data (Landoski 2016) shows that most stands have a Stand Density Index (SDI) >350 which puts them above the lower limit of the zone of self-thinning for mixed conifer stands and very close to the zone (SDI >365) where bark beetle outbreaks are likely to occur in ponderosa pine stands (Oliver 1995).

Figure 9. Overly dense stand of white fir with old dead and down from 1987 – 1992 drought.

Figure 10. Large Jeffrey pine stump within dense stand of white fir.

Most stands have also experienced a species composition shift from shade intolerant ponderosa and Jeffrey pine to more shade tolerant white fir in the absence of fire (Figures 10 and 11). This phenomenon is detailed for the nearby southern Warner Mountains by Vale (1977) and summarized for low and mid montane zones of the entire Warner Mountains by Riegel et al (2006). Vale also described the near complete lack of yellow pine regeneration associated with the successful establishment of white fir; a condition that persists today in native stands. Egan et al (2010) describes the current dominance of white fir over ponderosa pine in Warner Mountain mixed species stands, especially in the younger age and smaller size classes. While this information was collected and analyzed for the Warner Mountains, the results are relevant to the Kresge project area due to it having the same types of stand conditions and species composition shifts occurring in the absence of fire.

Figure 11. Legacy pine among a white fir understory.

White fir is now abundant on many sites that are considered high to extreme risk for mortality during drought periods. The mortality resulting from the current drought as well as previous droughts provides ample proof that these areas do not support healthy stands of white fir over the long-term. In the Kresge project area, fir engraver beetle-caused tree mortality has generally increased since 2010, accelerating to outbreak levels from 2014 through 2016 (Table 1). This outbreak is likely to continue until precipitation levels return to normal or white fir are significantly depleted by bark beetles and/or stand replacing wildfire.

Table 1. Acres with mortality, estimated dead trees per acre and estimated total # of dead trees from R5 Aerial Detection Surveys and Palmer Hydrologic Drought Index (PHDI) (average of CA Divisions 2 and 3[1]) by water year (Oct-Sept) within the Kresge project area.

Year	Acres	Dead Trees/Acre	Total # of Dead Trees	PHDI[2]
2016	5,527	21.7	119,764	-1.28*
2015	5,740	11.8	67,829	-3.34
2014	5,188	8.9	46,363	-3.56
2013	676	0.3	217	-2.16
2012	1,282	4.5	5,803	-0.59
2011	830	3.5	2,869	2.78
2010	803	4.3	3,456	-0.14
2009	53	2.2	114	-2.98
2008	130	2.7	346	-3.16
2007	118	1.3	147	-3.17

[1] California Divisions 2 and 3 encompass most of northeastern California. The Kresge project is generally on the border between these two zones.
[2] PHDI values ranging from -2.00 to -2.99 are considered moderate drought conditions. Severe drought conditions range from -3.00 to -3.99 and extreme drought conditions are below -4.00.
*Value calculated through November 2016

White fir that succumb to fir engraver beetle attacks are typically predisposed by other factors that compromise their health and vigor. In the Kresge project area, high stand density, prolonged drought, trees growing off site, dwarf mistletoe and Heterobasidion root disease are all contributing factors in declining tree health and mortality. White fir trees in the Kresge project area will remain susceptible to high levels of mortality until current drought conditions subside. More top kill and additional whole tree mortality should be expected next summer due to fir engraver beetle attacks sustained in 2016.

Nearly all of the project area receives less than 30 inches of annual precipitation and no area receives more than 40 inches of annual precipitation. Thirty inches is below what is generally required for healthy white fir forests to exist over the long-term. Therefore, even at the lowest stocking levels, white fir growing on these sites are at a high to extreme risk for fir engraver beetle-caused mortality during periods of drought. Even in stands that receive between 30 and 40 inches, the risk of mortality during drought is still considered medium.

The distribution of both white fir and white fir mortality are strongly influenced by the mean annual precipitation. The lower limit of precipitation in the natural range of white fir is about 20 inches (Fowels, H.A. 1965). The isohyetal map of mean annual precipitation provided in this report (Figure 2) can be used to rate the risk of white fir mortality (Schultz 1994).

Low risk: 40+ inches annual precipitation **(~0% of Kresge Project)**. These areas easily support stands of white fir. Mortality will be low, even during drought periods. Thinning will increase the rate of tree growth, but will show only slight differences in tree mortality.

Medium Risk: 30-40 inches of annual precipitation **(~13% of Kresge Project)**. Stands in these areas often have a high percentage of white fir that may achieve a considerable age and size.

Prolonged drought may cause mortality of 5-10% of the stems. Periodic thinning which concentrates on removing white fir ingrowth will lower mortality by maintaining a more sustainable amount of biomass, as well as promoting a more stable mixed species stand.

High Risk: 25-30 inches of annual precipitation **(~37% of Kresge Project**). In the absence of fire, these areas have stands which are dominated by densely stocked, small diameter white fir. The species distribution by age class shows an increase in the relative percentage of white fir in these stands following fire suppression. Prolonged drought may cause mortality in excess of 50% of the stems. The risk of mortality can be lowered by thinning to a wide spacing prior to the onset of drought, and by promoting a mix of species that are native to the site. *Note: this zone within the Kresge project includes larger diameter white fir that have also established following fire suppression. These trees should be targeted for removal as well as the smaller diameter white fir stems in order to establish and maintain a pine, fire-adapted system.*

Extreme risk: 20-25 inches of annual precipitation **(~50% of Kresge Project**). In some cases the shade tolerant trees may live long enough to achieve an intermediate or co-dominant crown position. Prolonged drought may cause mortality of 80-85% of the stems. In stands where the total stocking of both overstory and understory is high, mortality may also occur in the pines. The risk of mortality may be lowered by managing groups of pine at wide spacing.

A white fir levels of growing stock study conducted by Cochran (1998) on the Deschutes and Fremont National Forests between 1983 and 1995 provides some additional information to consider when managing white fir in lower precipitation areas. Plots were thinned in 1982 and again in 1985 to a residual stand density index (SDI) of 112, 168, 224 or 280. These corresponded to growing stock levels of 20, 30, 40 or 50 percent of normal density. Elevations for his study plots ranged from 4,500 to 5,900 feet with average annual precipitation ranging from 16 to 31 inches. A general drought prevailed over the study areas from the late 1970's to the mid 1990's and mortality between 1991 and 1995 destroyed the study. Mortality on Blocks 2, 3 and 4 of the study was attributed to fir engraver beetles. Mortality from fir engraver beetles appeared to increase with increasing stand densities and was above acceptable levels even at the lowest stand density (20 percent of density considered normal for white fir).

From Cochran 1998:

"Healthy stands of white fir grow very rapidly, produce a dense crown cover, and are visually pleasing. These results, however, raise doubts about growing white fir stands on sites with mean annual precipitation rates below 32 inches even if stand densities are kept very low. The four widely scattered stands represented in this study apparently grew well for more than 60 years and reached commercial size before severe mortality occurred. Where significant amounts of white fir are present, managers need the ability to manipulate stand composition to minimize mortality. Future stands on similar sites should have a large component of ponderosa pine and should be managed by using ponderosa pine stocking guides (Cochran and others 1994). These density levels would allow the individual fir trees, intermingled with pine, to reach commercial size at fairly young ages. If drought, disease outbreaks, or severe insect infestations occur, the white fir could be removed, leaving ponderosa pine on the site. Ponderosa pine quickly responds to new growing space even at old ages and would quickly take advantage of the available site resources.

Ferrell (1978) reports that trees under high moisture stress (-20 bars dawn xylem pressure or higher negative pressures) for protracted summer periods are more susceptible to successful fir engraver attacks than are trees under less stress. If prolonged droughts are forecast, removal of most of the white fir on drier sites may be advisable. This would prevent the buildup of fir engraver populations that could migrate to moist sites and inflict heavy damage where, historically, white fir has survived dry periods."

In a Warner Mountain study by Egan et al (2010), the density of fir engraver beetle-caused tree mortality was greater in unthinned versus thinned mixed conifer stands but the percentage of mortality relative to available host trees was similar. This further suggests that white fir growing in high risk sites (based on average annual precipitation) are susceptible to drought and fir engraver-beetle caused mortality regardless of stocking levels.

From Egan et al (2010):

"Our findings varied in mixed conifer areas as the density of, but not percent, FEN (fir engraver beetle)-caused mortality was reduced in thinned areas. These results do not support the use of thinning to reduce percent mortality or the relative number of residual white fir trees susceptible to FEN-caused mortality during times of drought. Conversely, this study does support the efficacy of thinning to reduce the density of mortality or absolute number of beetle-killed trees in mixed conifer stands exposed to drought conditions. The density of residual white fir host and elevation (likely a proxy for water availability) were important factors associated with white fir mortality in our study. These findings indicate thinning effectiveness in reducing fir mortality was directly proportional to the amount of post-treatment density white fir retained. Thus, our findings support discriminating against residual fir and retaining a greater pine component, similar to historic compositions (Vale, 1977), during thinning treatments to reduce the density of FEN-caused mortality even during periods of drought."

Several Forest Health Protection reports since 1994 have also identified unhealthy white fir stand conditions on the Modoc National Forest and the need for thinning (FHP reports available upon request). Most of these reports concurred that without treatment, the trend for most stands of increasing stand density, high levels of insect and disease activity and elevated levels of tree mortality would likely continue until a major disturbance event such as a stand replacing fire occurred. Schultz (1994) recommended thinning white fir stands on the Big Valley RD to manage for pine as a more sustainable stand structure; stating, "Unless these areas are being managed for habitat for a species which is dependent on small diameter dead white fir, or there is an economic market for small diameter white fir, then it would promote a more sustainable stand structure to manage for pine."

Predicted climate change is likely to impact trees growing in the Kresge project area over the next 100 years. Although no Modoc National Forest specific climate change models are available at this time, there is a general consensus among California models that summers will be drier than they are currently. This prediction is based on the forecasted rise in mean minimum and maximum temperatures and remains consistent regardless of future levels of annual precipitation (K. Merriam and H. Safford, *A summary of current trends and probable future trends in climate and climate-driven processes in the Sierra Cascade Province, including the Plumas, Modoc, and*

Lassen National Forests). The risk of bark beetle-caused tree mortality will likely increase for all conifer species under this scenario, especially drought intolerant white fir. Improving the resilience of stands to future disturbance events through density, size class and species composition management will be critical to maintaining a healthy forested landscape.

Considerations for thinning treatments

Low to mid elevation white fir and mixed conifer stands should be managed for the pine component as much as possible. This includes all white fir dominated stands with a ponderosa/Jeffrey pine component. This will likely require a change from the current mixed conifer or white fir stand typing in many areas to yellow pine, better representing historic species compositions and desired future conditions. Having the ability to significantly reduce stand density and the abundance of white fir is critical to successful ecological restoration within the project area.

Thinning stands without significantly reducing stocking levels and the abundance of white fir will not likely result in a change in trajectory towards a pine dominated fire-adapted condition. A high residual component of white fir will continue to produce abundant seed, increasing the number of white fir seedlings relative to pine seedlings. Subsequent and frequent prescribed fire can help change the trajectory of seedling establishment towards pine but its use is often hampered by lack of appropriate burning conditions, air quality concerns or adequate resources for implementation. Even if prescribed burning is accomplished, is not likely to significantly reduce the number of larger diameter, seed producing white fir in thinned stands due to generally thicker bark and higher crown base heights.

When planning thinning treatments, it should be recognized that the target stand density and species composition is an average to be applied across the landscape and some variability may be desired to increase heterogeneity. Individual high-value trees, such as mature pines, and drier areas dominated by ponderosa/Jeffrey pine should benefit by having the stocking reduced to lower levels. Allowing for denser tree spacing and pockets of higher canopy cover may be desirable around potential wildlife trees, such as forked and/or broken-topped trees. Higher concentrations of white fir can be retained at higher elevations that receive >30" of average annual precipitation or on north facing slopes that receive 25 to 30" of average annual precipitation. Tree removal should include trees heavily infected with dwarf mistletoe, root disease and trees infested with bark beetles. Small group harvest could also be utilized to remove white fir that are within known Heterobasidion root disease centers or are heavily infested with dwarf mistletoe. This would create openings that could be planted with ponderosa and Jeffrey pine. These types of prescriptions would be consistent with 2014 Farm Bill Section 602(d)(1) direction that allows the implementation of projects "….to reduce the risk or extent of, or increase the resilience to, insect or disease infestation in the areas."

In most cases, thinning to a relative density of 25 - 40% (relative to the maximum Stand Density Index, or SDI) for a specific conifer species or for a weighted composition of conifer species will effectively reduce competition for limited water and nutrients and reduce the susceptibility to future bark beetle-caused tree mortality. This approach will also increase the longevity of treatments as they should stay below 60% relative density, the general threshold for self-

thinning, for many years. For the Kresge project area, the District should consider basing relative density targets on the pine component of most mixed conifer and white fir stands. A possible target could be a maximum stand density index of 450 for ponderosa pine as suggested by Long and Shaw 2005. In areas where white fir will remain the dominant stand component, due to more favorable site conditions for the species, a maximum stand density index of 550 as described by Long and Shaw (2012) may be appropriate.

The latest peer-reviewed research on Jeffrey pine stocking as it relates to Jeffrey pine beetle-caused mortality (Egan et al 2016) and a FHP report for the same study (Egan et al 2009) suggest stocking levels that are at or below SDI 210 (corresponded to < 125 sq.ft./acre of basal area in study plots) to reduce tree mortality during droughts and high bark beetle population pressure. Stocking levels of SDI 110 (corresponded to <80 sq.ft./acre of basal area in study plots) had no Jeffrey pine beetle-caused mortality during the Jeffrey pine beetle outbreak monitored during the study.

It is recommended that a registered borate compound be applied to all freshly cut conifer stumps >14" in diameter to reduce the chance of creating new infection centers of *Heterobasidion irregulare* and *H. occidentale* formerly referred to as P-type and S-type annosus root disease, through harvest activity. An exception to this recommendation would be in yellow pine/white fir stands or more pure white fir stands if there is already a high level of Heterobasidion root disease present as treating white fir stumps in heavily infected stands is ineffective.

Considerations for Douglas-fir tussock moth

Douglas-fir tussock moth (O*rgyia pseudotsugata*) caused moderate to high levels of white fir defoliation within and adjacent to the Kresge project area in 1999 and 2000. This resulted in top-killing and mortality of some white fir.

The Kresge project area has become very dense with white fir through past management activities and with the exclusion of fire over the past 100+ years. With such a high percentage of white fir in the area, shade intolerant species such as ponderosa pine and Jeffrey pine, as well as many shrub species, tend to decline due to competition for sunlight, water and nutrients. Higher percentages of white fir in mixed conifer stands increase susceptibility to defoliation events caused by the Douglas-fir tussock moth. In California, white fir is the preferred host species for the Douglas-fir tussock moth and outbreaks have tended to occur on ridge tops, upper slopes and generally poorer sites with high percentages of white fir. Past outbreaks where heavy defoliation has occurred resulted in approximately 20 - 25 % mortality with lower levels of top kill. Management practices that increase stand vigor, increase species diversity by reducing the white fir component and promote even aged stand characteristics for the residual white fir component will increase resistance to Douglas-fir tussock moth.

Considerations for Rx fire

If prescribed fire is used as a follow-up treatment to stand thinning or as a standalone treatment, unacceptable levels of large diameter pine mortality may occur depending on management objectives. This mortality most often occurs as a direct result of cambium or crown injury to

individual trees during the fire. Mature ponderosa are susceptible to mortality during prescribed burns because of the deep duff and litter that has accumulated at their base in the absence of fire. These duff mounds typically burn at a slow rate, while maintaining lethal temperatures, causing severe cambium injury. To protect individual large diameter pine from lethal cambium injury, raking the duff away from the bases of these trees before burning (within 24" of the bole and down to mineral soil) is recommended.

White fir occurring in nearly pure stands tend to have very high levels of course woody debris on the forest floor as a result of downed logs from self-thinning, the continual shedding of branches and the remaining stems from old stands of brush that have been overtopped and killed by dense fir canopies. These types of stands produce tremendous amounts of heat on the ground surface and often cause severe injuries to the boles and crowns of standing trees, especially to smaller diameter trees. If high post-burn mortality levels in true fir stands, resulting in openings and possibly additional heavy fuel loading, is not an acceptable condition, than fuel treatments such as hand or tractor piling should be considered prior to or in place of prescribed fire. This is especially important in roadside units due to the potential for some fire-injured true fir to deteriorate into an unstable and hazardous condition.

Potential for funding through the Western Bark Beetle Program

Forest Health Protection may be able to assist with funding, including NEPA activities, for thinning within the Kresge project area. Thinning treatments that reduce stand density and change species compositions sufficient to lower the risk to bark beetle-caused mortality would meet the minimum requirements for Western Bark Beetle Program funding and would be supported by this evaluation. If you are interested in this competitive funding please contact me for assistance in developing and submitting a proposal.

If you have any questions regarding this report and/or need additional information please contact Danny Cluck at 530-252-6431.

/s/ Danny Cluck

Daniel R. Cluck
Forest Entomologist
NE CA Shared Service Area

cc: John Landoski, District Culturist, Big Valley/Doublehead RD
Bill Moore, Forest Vegetation Manager, Modoc SO
Forest Health Protection, Regional Office

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Insect and Disease Information

Jeffrey pine beetle

The Jeffrey pine beetle is the principle bark beetle found attacking Jeffrey pine, which is its only host. It is a native insect occurring from southwestern Oregon southward through California and western Nevada to northern Mexico. The beetle normally breeds in slow-growing, stressed trees. The beetles prefer trees which are large, mature, and occur singly rather than in groups. Yet when an epidemic occurs, the beetle may attack and kill groups of trees greater than 8 inches in diameter, regardless of age or vigor. Often the beetle infests lightning-struck or wind-thrown trees, but does not breed in slash.

Evidence of Attack
Presence of the beetle is usually detected when the foliage changes color. The color change of the foliage is related to the destruction of the cambium layer by the beetle. Generally, the top of the crown begins to fade in a slow sequence, with the needles turning from greenish yellow, to sorrel, and finally to reddish brown. By the time the tree is reddish brown, the beetles have usually abandoned the tree. Another sign of beetle attack is large, reddish pitch tubes projecting from the bark of the infested tree. If examined carefully, pitch tubes can be detected on infested green trees prior to crown fade. Jeffrey pine beetles have a distinctive "J" shape egg gallery pattern on the inner bark. Larval mines extend across the grain and end in open, oval-shaped pupal cells.

Life Stages and Development
The Jeffrey pine beetle is one of the larger pine bark beetles in California. The beetle has a 4 life stages, egg, larva, pupa, and adult. The adults are stout, cylindrical, black, and approximately five-sixteenths of an inch long when mature. The egg is oval and pearly-white. The larva is white, legless, and has a yellow head. The pupa is also white but is slightly smaller than the mature larva. The life cycle is normally completed in one year in the northern part of the range, but in the southern part, two generations per year may occur. The principle period of attack is in June and July, but attacks also are frequent in late September and early October. Similar to other *Dendroctonus* species, Jeffrey pine beetles use pheromones that attract other beetles to a tree, causing a mass attack that tends to overcome the tree's natural resistance. Blue stain fungi are associated with Jeffrey pine beetle attacks and aid in overcoming the tree's defenses.

Conditions Affecting Outbreaks
Normally the Jeffrey pine beetle is kept in check by its natural enemies, climatic factors and the resistance of its host. Similar to other *Dendroctonus* species, the availability of suitable host material is a key factor influencing outbreaks. Healthy trees ordinarily produce abundant amounts of resin, which pitches out attacking beetles. When deprived of moisture, or stressed by other factors such as disease or fire injury, trees cannot produce sufficient resin flow and become susceptible to successful beetle attacks

Western Pine Beetle

The western pine beetle, *Dendroctonus brevicomis*, has been intensivly studied and has proven to be an important factor in the ecology and management of ponderosa pine thoughout the range of the host species (Miller and Keen 1960). This insect breeds in the main bole of living ponderosa pine larger than about 8 inches DBH. Normally it breeds in trees weakened by drought, overstocking, root disease, dwarf mistletoe or fire. Adult beetles emerge and attack trees continuously from spring

through fall. Depending on the latidude and elevation, there can be from one to four generations per year.

Evidence of Attack
Initial attacks are made about mid-bole and subsequent attacks fill in above and below. Pitch tubes are formed on the tree trunk around the entry holes. Successful pitch tubes are red-brown masses of resin and boring dust. Relativly few, widely scattered white pitch tubes usually indicate that the attacks were not successful and that the tree should survive. Pheremones released during a successful attack attract other conspecifics. Attracted beetles may then spill over into nearby apparently healthy trees and overwhelm the tree with sheer numbers.

Life Stages and Development
These beetles pass thorugh the egg, larval, pupal and adult stages during a life cycle that varies in length dependent primarily on temperature. Adults bore a sinuous gallery pattern in the phloem and the female lays eggs in niches along the sides of the gallery. The larvae are small white grubs that first feed in the phloem then mine into the middle bark where they complete most of their development. Bluestain fungi inoculates the tree during successful attacks, blocking trachids and vessicles which contribute to the rapid tree mortality associated with bark beetle attacks.

Conditions affecting Outbreaks
Outbreaks of western pine beetle have been observed, and surveys made, in pine regions of the Westsince 1899 (Hopkins 1899; cited in Miller and Keen 1960). An insect survey completed in 1917 in northern California indicated that over 25 million board feet of pine timber had been killed by bark beetles.Information from surveys conducted in the 1930's indicated enormous losses attributed to the western pine beetle around that time. During the 1930's outbreak, most of the mortality occurred in stands of mature or overmature trees of poor vigor (Miller and Keen 1960). Group kills do not typically continue to increase in size though successive beetle generation as is typical with Mountain Pine Beetle and Jeffreay Pine Beetle. Rather, observations indicate that emerging beetles tend to leave the group kill area to initiate new attacks elsewhere.

The availability of suitable host material is a key condition influencing western pine beetle outbreaks. In northeastern California, drought stress may be the key condition influencing western pine beetle outbreaks. When healthy trees undergo a sudden and sever moisture stress populations of western pine beetle are likely to increase. Healthy trees ordinarily produce abundant resin, which pitch out attacking beetles, but when deprived of moisture, stressed trees cannot produce sufficient resin to resist the attack. Any condition that results in excessive demand for moisture, such as inter-tree completion, competing vegetation, or protracted drought periods; or any condition that reduces the ability of the roots to supply water to the tree, such as mechanical damage, root disease or soil compaction, can cause moisture stress and increase susceptibility to attack by the western pine beetle. Woodpeckers, predacious beetles, and low temperatures act as natural control agents when beetle populations are low (endemic populations).

Fir engraver beetle

The fir engraver attacks red and white fir in California. Fir engraver adults and developing broods kill true firs by mining the cambium, phloem, and outer sapwood of the bole, thereby girdling the tree. Trees greater than 4" in diameter are attacked and often killed in a single season. Many trees, weakened through successive attacks, die slowly over a period of years. Others may survive attack as evidenced by old spike-topped fir and trees with individual branch mortality. Although many other species of bark

beetles cannot develop successful broods without killing the tree, the fir engraver beetle is able to attack and establish broods when only a portion of the cambium area has been killed.

Evidence of Attack
Fir engravers bore entrance holes along the main stem, usually in areas that are > 4" in diameter. Reddish-brown or white boring dust may be seen along the trunk in bark crevices and in spider webs. Some pitch streamers may be indicative of fir engraver attacks; however, true firs are known to stream pitch for various reasons and there is not clear evidence that pitch streamers indicate subsequent tree mortality or successful attack. Resin canals and pockets in the cortex of the bark are part of the trees defense mechanism. Beetle galleries that contact these structures almost always fail to produce larval galleries as the adults invariably abandon the attack. Pitch tubes, often formed when bark beetles attack pine, are not produced on firs.

Adults excavate horizontal galleries that engrave the sapwood; the larval galleries extend at right angles along the grain. Attacks in the crown may girdle branches resulting in individual branch mortality or "flagging". Numerous attacks over part or the entire bole may kill the upper portion of the crown or the entire tree. A healthy tree can recover if sufficient areas of cambium remain and top-killed trees can produce new leaders. The fir engraver is frequently associated with the roundheaded fir borer and the fir flatheaded borer.

Life Stages and Development
In the summer, adults emerge and attack new host trees. The female enters the tree first followed by the male. Eggs are laid in niches on either side of the gallery. Adult beetles carry the brown staining fungi, *Trichosporium symbioticum*, into the tree that causes a yellowish-brown discoloration around the gallery. The larvae mine straight up and down, perpendicular to the egg gallery. Winter is commonly spent in the larval stage, with pupation occurring in early spring. In most locations, the fir engraver completes its life cycle in 1 year; however at higher elevations 2 years may be required.

Conditions Affecting Outbreaks
Fir engravers bore into any member of the host species on which they land but establish successful galleries only in those that have little or no resistance to attack. Populations of less aggressive species like fir engraver are likely to wax and wane in direct relationship to the stresses of their hosts. Drought conditions often result in widespread fir mortality; however, attempting to determine when outbreaks will occur is difficult. Lowered resistance of trees appears to be a contributing factor. Overstocking and the increased presence of fir on sites that were once occupied by pine species may also contribute to higher than normal levels of fir mortality. Several insect predators, parasites and woodpeckers are commonly associated with the fir engraver and may help in control of populations at endemic levels.

Douglas-fir tussock moth

The Douglas-fir tussock moth is an important defoliator of true firs, primarily white fir, in California. Some level of outbreak by Douglas-fir tussock moth has been recorded in California about every 10 years. Outbreaks appear to develop almost explosively, and then usually subside abruptly after a year or two. Defoliation by the tussock moth kills or top-kills many trees, weakens additional trees that can be eventually killed by bark beetles, and may retard tree growth for several years.

Usually the first indication of attack appears in late spring. Larvae from the newly hatched eggs feed on current year's foliage, causing it to shrivel and turn brown. Older larvae may feed on both current and old foliage, although current needles are preferred. Defoliation occurs first in the tops of the trees and the outermost portions of the branches, and then in the lower crown and farther back on the branches.

The adult male is a gray-brouwn to black-brown moth with feathery antennae and a wingspread of 1 to 1 1/4 inches. The forewings are gray brown and have two distinct, irregular dark bars and two vague whitish spots. The hindwings are a contrasting brown. The female has tiny rudimentary wings, small threadlike antennae, and a large abdomen. Young larvae are 1/8 to 1/4 inch long and have long, fine body hairs which later develop into tufts. Mature larvae are up to 1 1/4 inches long and very colorful. Two long, dark tufts or pencils of hair similar to horns are located right behind the head. Four dense, buff colored tussocks are located forward along the middle of the back. The rest of the body except for the legs and head, is covered with short hairs radiating from red, buttonlike centers.

The tussock moth produces one generation each year. Females mate soon after they emerge from their pupal cocoon. Egg hatch in May or early June coincides with bud burst and shoot elongation of the host trees. The larvae pass through four to six instars and pupate toward the end of the summer. The pupal stage lasts from 10-18 days depending on temperature.

Many natural controls exist that keep the number of tussock moths low most of the time. If population levels are causing unacceptable resource damage, alternate methods of control are available. Management recommendations to prevent tree damage from tussock moth outbreaks involve four major activities: early detection, evaluation, suppression, and prevention. An early detection pheromone trap monitoring system is in place in California, however prevention is the ultimate goal of pest management. Silvicultural systems that reduce the number of susceptible hosts and decrease the multi-storied characteristics of host stands are recommended to prevent outbreaks. There is some indication that fir growing in pine sites an fir stands on warm, dry sites are most susceptible to damage.

Heterobasidion root disease

Heterobasidion spp. is a fungus that attacks a wide variety of woody plants. All western conifer species are susceptible. Madrone (*Arbutus menziesii*), and a few brush species (*Arctostaphylos spp.* and *Artemisia tridentata*) are occasional hosts. Other hardwood species are apparently not infected. The disease has been reported on all National Forests in California, with incidence particularly high on true fir in northern California, in the eastside pine type forests, and in southern California recreation areas.

Heterobasidion root disease is one of the most important conifer diseases in Region 5. Current estimates are that the disease infests about 2 million acres of commercial forestland in California, resulting in an annual volume loss of 19 million cubic feet. Other potential impacts of the disease include: increased susceptibility of infected trees to attack by bark beetles, mortality of infected trees presently on the site, the loss of the site for future production, and depletion of vegetative cover and increased probability of tree failure and hazard in recreation areas.

During periods favorable to the fungus, fruiting bodies (conks) form in decayed stumps, under the bark of dead trees, or under the duff at the root collar. New infection centers are initiated when airborne spores produced by the conks land and grow on freshly cut stump surfaces. Infection in true fir may also occur through fire and mechanical wounds, or occasionally, through roots of stumps in the absence of surface colonization. From the infected stump surface, the fungus grows down into the roots and then spreads via root-to-root contact to adjacent live trees, resulting in the formation of large disease centers. These infection centers may continue to enlarge until they reach barriers, such as openings in the stand or groups of resistant plants. In pines, the fungus grows through root cambial tissue to the root crown where it girdles and kills the tree. In true fir and other non-resinous species, the fungus sometimes kills trees, but more frequently is confined to the heartwood and inner sapwood of the larger roots. It then eventually extends into the heartwood of the lower trunk and causes chronic decay and growth loss.

Heterobasidion root disease in western North America is caused by two species: *Heterobasidion occidentale* (also called the 'S' type) and *H. irregulare* (also called the 'P' type). These two species of *Heterobasidion* have major differences in host specificity. *H. irregulare* ('P' type) is pathogenic on ponderosa pine, Jeffrey pine, sugar pine, Coulter pine, incense cedar, western juniper, pinyon, and manzanita. *H. occidentale* ('S' type) is pathogenic on true fir, spruce and giant sequoia. This host specificity is not apparent in isolates from stumps; with *H. occidentale* being recovered from both pine and true fir stumps. These data suggest that infection of host trees is specific, but saprophytic colonization of stumps is not. The fungus may survive in infected roots or stumps for many years. Young conifers established near these stumps often die shortly after their roots contact infected roots in the soil.

Dwarf mistletoe

Dwarf mistletoes (*Arceuthobium* spp.) are parasitic, flowering plants that can only survive on living conifers in the Pinaceae. They obtain most of their nutrients and all of their water and minerals from their hosts.

Dwarf mistletoes spread by means of seed. In the fall the fruit ripen and fall from the aerial shoots. The seeds are forcibly discharged. The seed is covered with a sticky substance and adheres to whatever it contacts. When a seed lands in a host tree crown, it usually sticks to a needle or twig, where it remains throughout the winter. The following spring the seed germinates and penetrates the twig at the base of the needle. For the next 2-4 years, the parasite grows within the host tissues, developing a root-like system within the inner bark and outer sapwood, and causing the twig or branch to swell. Aerial shoots then develop and bear seed in another 2-4 years.

Dispersal of dwarf mistletoe seeds is limited to the distance the seeds travel after being discharged. From overstory to understory, this is usually 20 to 60 feet, but wind may carry them as far as 100 feet from the source. A rule of thumb is that the seeds can travel a horizontal distance equal to the height of the highest plant in an infected tree. There is some evidence that long distance spread of dwarf mistletoe is occassionaly vectored by birds and animals.

Vertical spread within tree crowns of most dwarf mistletoes is limited to less than one foot per year because of foliage density. Because of the thin crowns of gray pine, however, the vertical rate of spread has been measured as being greater than 2 feet per year. This rate of spread equalled or exceeded the rate of height growth of infected trees.

Dwarf mistletoes are easy to identify because they are generally exposed to view within a tree's crown. Signs of infection include the yellow-green to orange mistletoe plants, basal cups on a branch or stem where the plants were attached and detached plants on the ground beneath an infected tree. Symptoms include spindle-shaped branch swellings, witches' brooms in the lower crown, and bole swellings.